Quantifying Groundwater Dependent Ecosystem Changes due to Water Availability and Management in Arid Environments with Landsat

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Motivation

- Groundwater dependent ecosystems (GDEs) sustain much of the of ecological biodiversity in arid environments
- Groundwater appropriations are increasingly being challenged due to capture of surface water and groundwater discharge
- Biological and hydrological plans to monitor capture could benefit from new Landsat science
- Our aim is to support GDE vegetation and water use monitoring using the Landsat archive, and develop efficient tools for land and water managers

Ruby Lake, Ruby Valley, NV

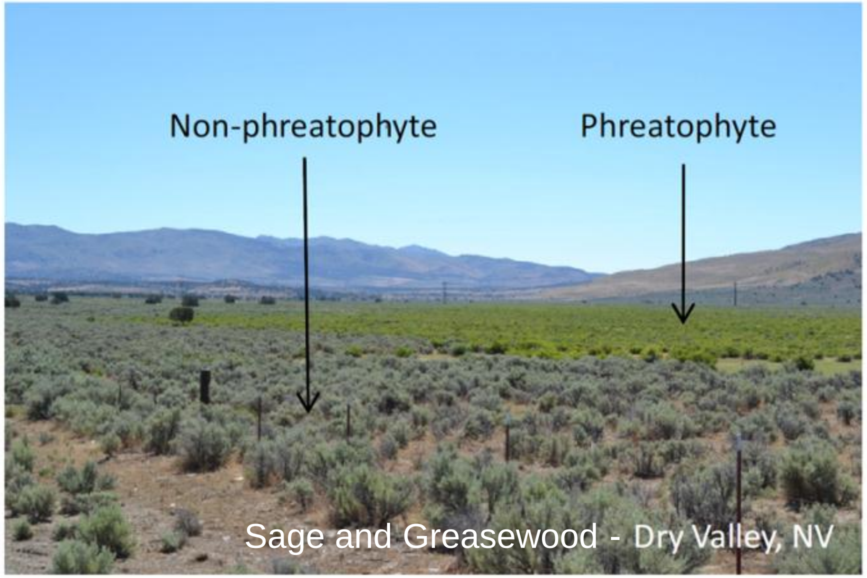
Lamoille Canyon, NV

Big Springs, Snake Valley, NV/UT

Groundwater Appropriation & Perennial Yield

- Groundwater law in many western US states allows for appropriation of groundwater for beneficial use, and is typically limited to the Hydrographic Basin's 'perennial yield'

- Nevada water words dictionary - "The perennial yield is the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir. The perennial yield cannot be more than the natural recharge of the groundwater reservoir and is usually limited to the maximum amount of natural discharge"

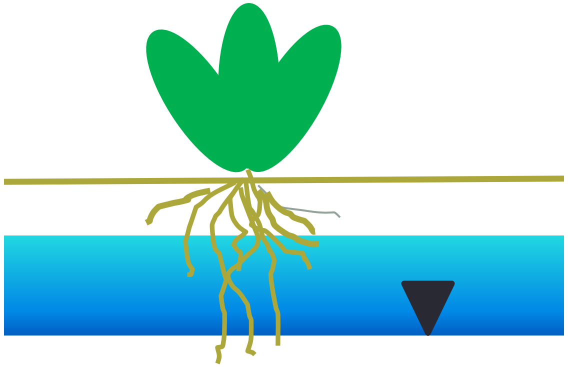


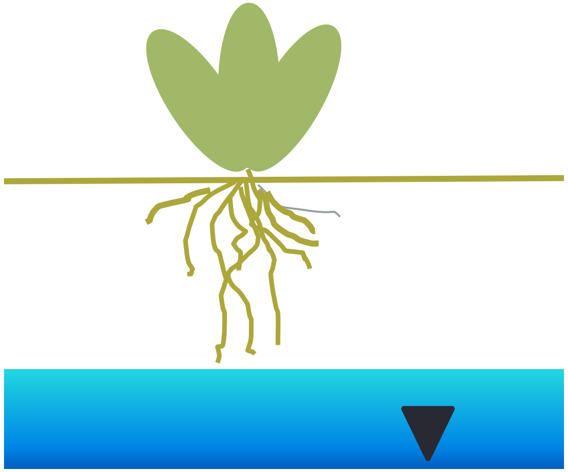
Capture of Groundwater Discharge

- Appropriation of the full perennial yield assumes capture all the natural groundwater discharge

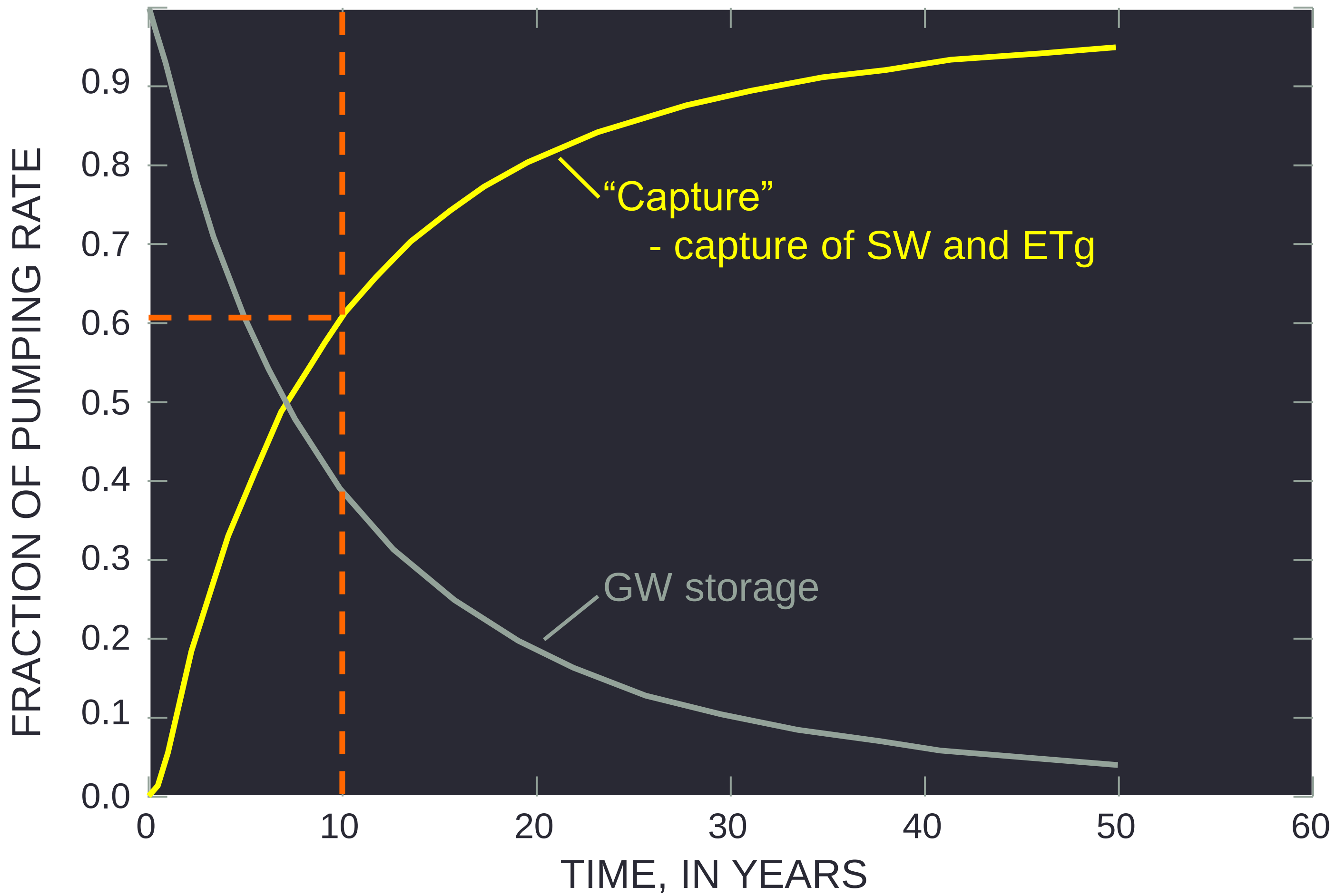
- Long-term groundwater pumping causes a lowering of the water table and reduces groundwater ET (ETg)
  - Capture of ETg is put to beneficial use (for humans)
  - Capture of ETg reduces vegetation vigor

- In most cases, groundwater appropriation is based on the ETg from phreatophyte vegetation





Sources of Water to a Pumped Well



Theis (1940) “All water discharged by wells is balanced by a loss of water somewhere else”

EDITORIAL

MANAGING WATER RESOURCES SYSTEMS: WHY "SAFE YIELD" IS NOT SUSTAINABLE

by Marios Sophocleous[a]

Although major gaps in our understanding of soil and water ecosystems still exist, of more importance are the gaps between what is known and what is applied. One such gap is in
the use of the concept of "safe yi
management. Despite being repeate
ture, SY continues to be used as t
water-management policies, leading
depletion, stream dewatering, and l
ecosystems.

Traditionally, "safe yield" has
ment and maintenance of a long-
amount of ground water withdraw
amount of recharge. Thus, SY limit
the amount that is replenished na
concept of SY ignores discharge fro
or equilibrium conditions, recharge
by discharge from the aquifer inte
Consequently, if pumping equals re
marshes, and springs dry up. Continued pumping in excess of recharge also eventually depletes the aquifer. This has happened in various locations across the Great Plains. Maps comparing the perennial streams in Kansas in the 1960s to those of the 1990s show a marked decrease in miles of streamflow in the western third of the state. (For more information on SY, see the edited volume by Sophocleous, 1997, "Perspectives on Sustainable
Development of Water Resources in
cal Survey, Bulletin 239, in press.)
concerned about aquifer drawdow
tion, both unrelated to the natura
irrelevance, natural recharge is often
to balance ground-water use under
such an attractive fallacy does not provide scientific credibility.

To better understand why "safe yield" is not sustainable yield, a review of hydrologic principles (concisely stated by Theis in 1940) is required. Under natural conditions, prior to development by wells, aquifers are in a state of approximate dynamic equilibrium: over hundreds of years, recharge equals discharge. Discharge from wells upsets this equilibrium by producing a loss from aquifer storage. A new state of dynamic equilibrium is reached only by an increase in recharge (induced recharge), a decrease in natural discharge, or a combination of the two. Initially, ground water pumped from the aquifer comes from storage, but ultimately it comes from induced recharge. The timing of this transition, which takes a long time by human standards, is a key factor in developing sustainable water-use policies. However, it is exceedingly difficult to distinguish between natural recharge and induced recharge to ascertain possible sustained yield. This is an area that needs further research. Calibrated stream-aquifer models could provide some answers in this regard.

[a]Senior Scientist, Kansas Geological Survey, The University of Kansas, 1930 Constant Ave., Lawrence, Kansas 66047-3726. The views expressed here are the author's and not necessarily those of the AGWSE, NGWA, and/or the Ground Water Publishing Company.

The concept of sustainable yield has been around for many years, but a quantitative methodology for the estimation of such yield has not yet been perfected. A suitable hydrologic basis for

our streams, but when we do, we learn that the streams were more than just containers of usable water.

A better definition of SY would address the sustainability of the system—not just the trees, but the whole forest; not just the fish, but the marine food chain; not just the ground water, but the running streams, wetlands, and all the plants and animals

Science will never know all there is to know. Rather than allowing the unknown or uncertain to paralyze us, we must apply the best of what we know today, and, at the same time, be flexible enough to allow for change and for what we do not yet know. Instead of determining a fixed sustainable yield, managers should recognize that yield varies over time as environmental conditions vary.

Our understanding of the basic principles of soil and water systems is fairly good, but our ability to use this knowledge to solve problems in complex local and cultural settings is relatively weak. Communication is vital. We need people who can transfer research findings to the field and who can also communicate water-users' needs to the researchers. Delivering a journal publication to a manager's desk is not sufficient to ensure that research results are quickly put into practice. I believe this breakdown in communication accounts for the persistence of such misguided concepts as SY in ground-water management today. Researchers increasingly must cross the boundaries of their individual disciplines, and they must look to their clients—the managers and water users—for help in defining a practical context for research. A strong public education program is also needed to improve understanding of the nature and complexity of ground-water resources and to emphasize how this understanding must form the basis for operating conditions and constraints. This is the only way to positively influence, for the long term, the attitudes of the various stakeholders involved.

"Despite being discredited repeatedly in the literature, safe yield continues to be used as the basis of water-management policies, leading to continued ground-water depletion, stream dewatering, and loss of wetland and riparian ecosystems."

"…if pumping equals recharge (or discharge), eventually streams, marshes, and springs dry up"

Stipulation Requirements for Hydrologic Monitoring

- Monitor stream / spring discharge
- Monitor vegetation vigor
- Maintain, update, and operate well-calibrated regional groundwater flow system numerical model
- Remote sensing, including both aerial photography and satellite imagery

“However, currently available technology does not provide sufficient precision to detect short-term changes in vegetation that may be induced by groundwater withdrawal at the fine scales necessary to meet the monitoring requirements of the Plan. Instead, permanent line transect data will be used to detect these fine-scale vegetation changes.”

Biological Monitoring Plan for the Spring Valley Stipulation

Photo by Kelly Douglas

February 2009

Biological Work Group

Stipulation Parties: Bureau of Indian Affairs
Bureau of Land Management
National Park Service
Southern Nevada Water Authority
U.S. Fish and Wildlife Service

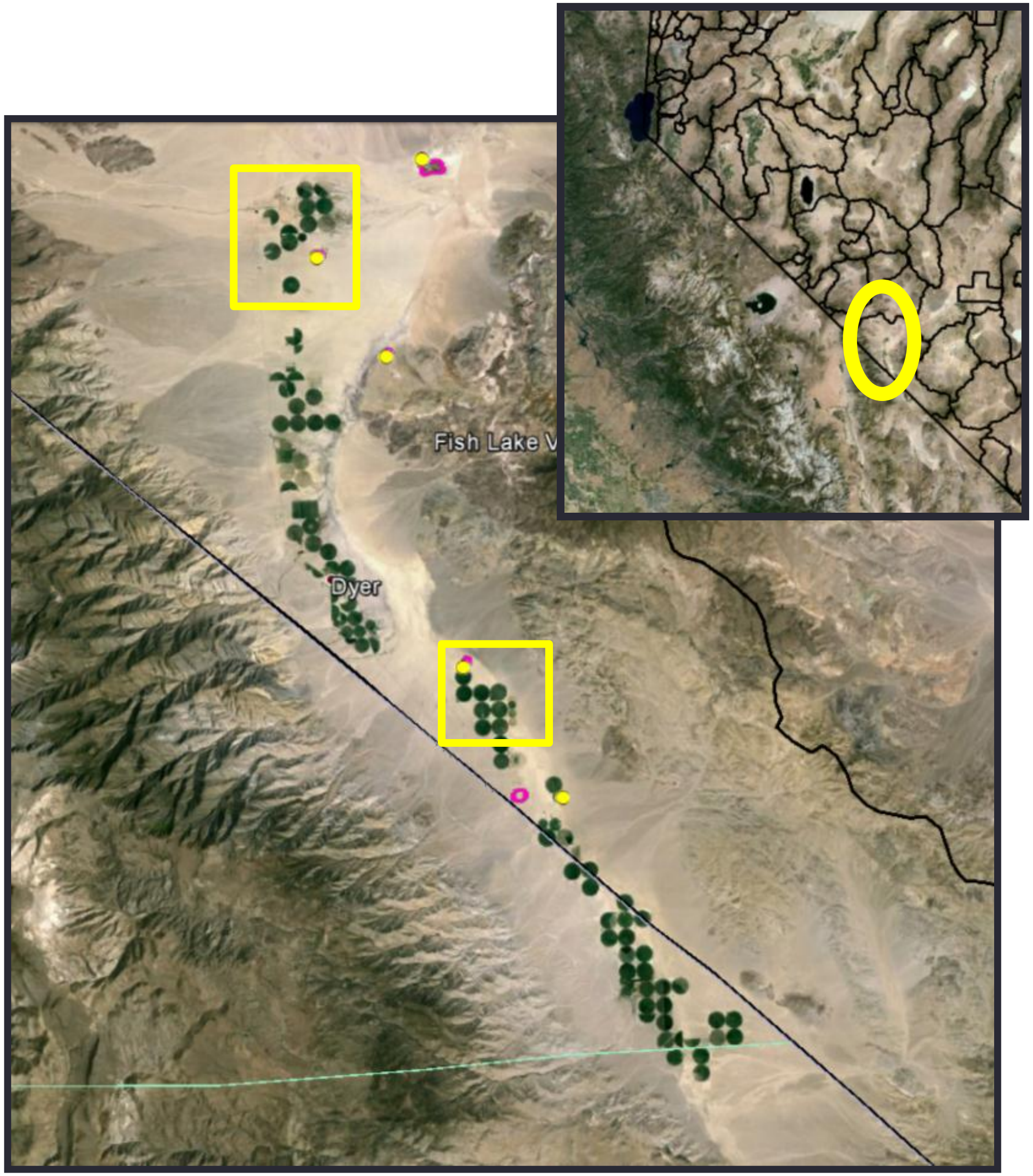
Invited Parties: Nevada Department of Wildlife
Utah Division of Wildlife Resources

Landsat for Short and Long-Term GDE Monitoring

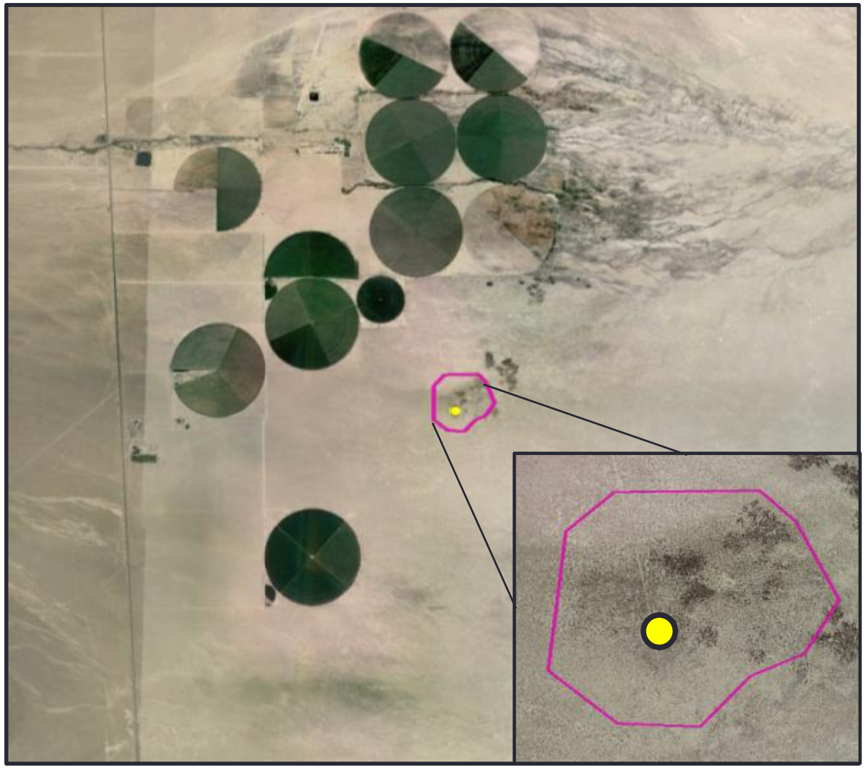
- Now days we can rely on the free archive of Landsat optical and thermal imagery and spatial climate data
- To determine if future vegetation changes are natural or anthropogenic, we need ~30+ years of data to evaluate the past (multiple drought cycles…)
- Having Landsat with cloud computing technology is rapidly changing the requirements for monitoring, and how and what we monitor
- The bottle neck is providing the ability for the public and regulatory agencies to perform long-term Landsat monitoring given archive computational requirements
- Google Earth Engine linked to Google App Engine can help with this…

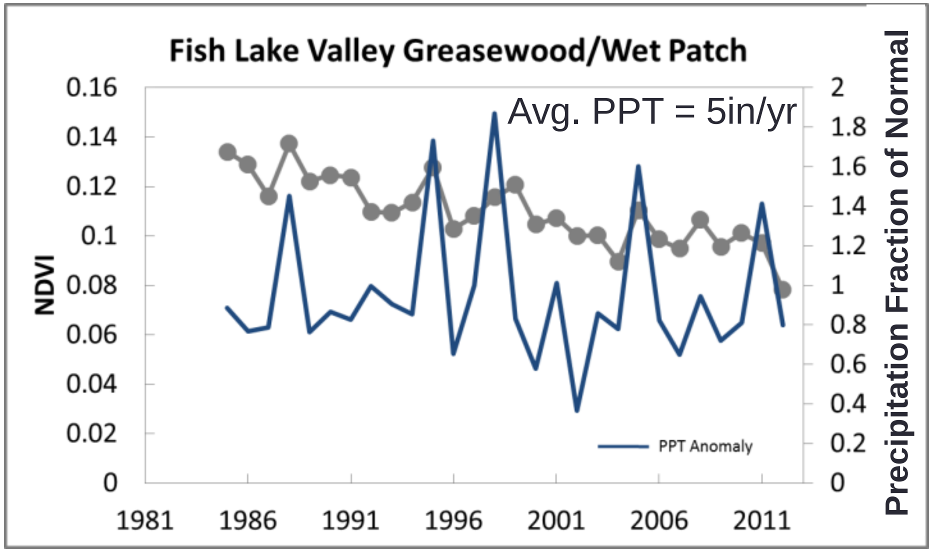
GW Pumping and Wetland / Greasewood Vegetation

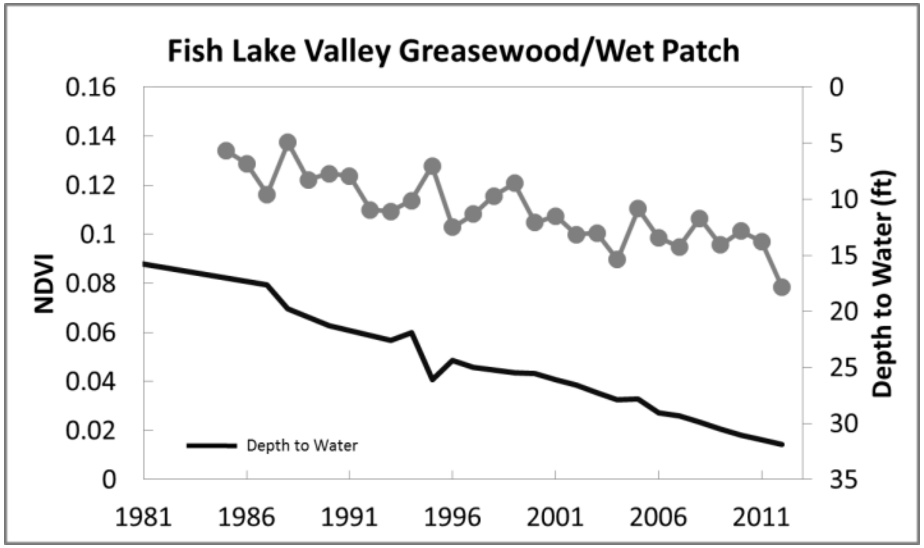
- Fish Lake Valley, NV example pairing Landsat NDVI with PPT and pumping
- Groundwater is primary source of water for irrigation in the valley
- Test – can we see changes in greasewood NDVI due to pumping?
- https://earthengine.google.org/#timelapse/v=37.82067,-118.03078,10.812,latLng&t=2.86



Result – GW Pumping & Greasewood

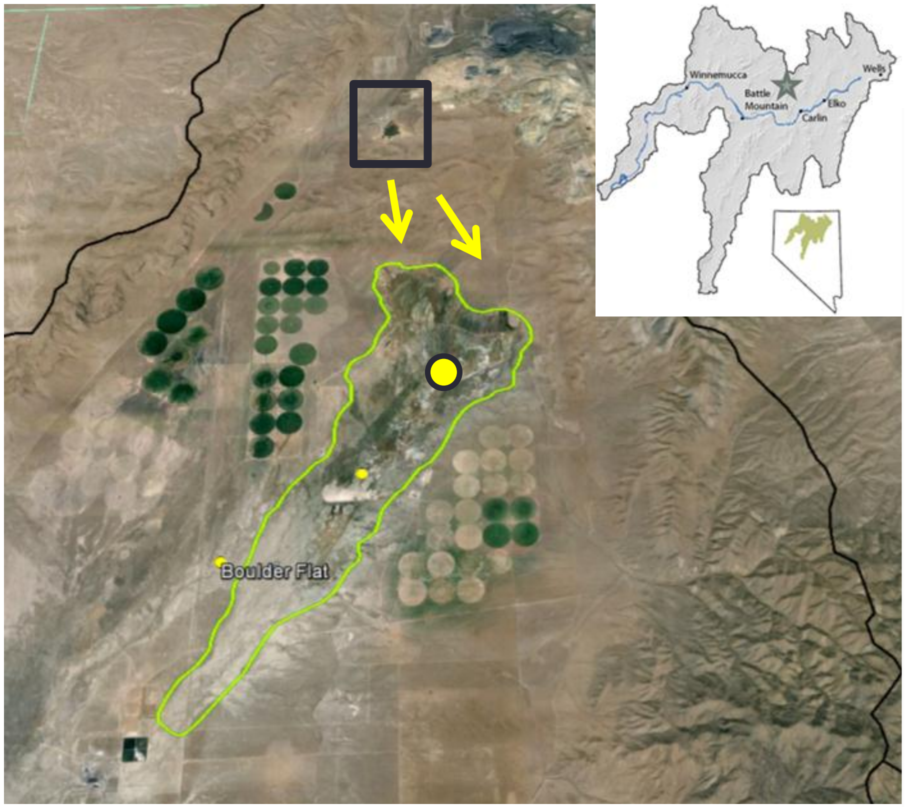


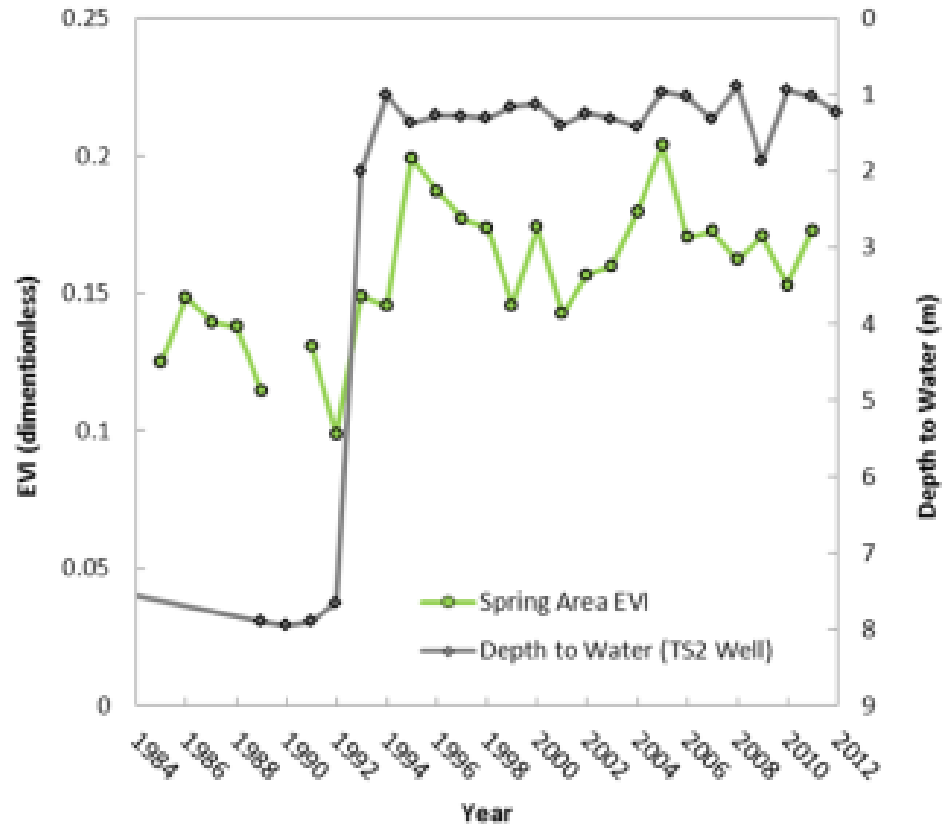




- Digitized polygon around well, ~ 0.25 miles across
- Vegetation largely comprised of greasewood
- Evaluated spatial average Aug-Sept NDVI, NLDAS PPT with Earth Engine
- GW levels declining & NDVI declining

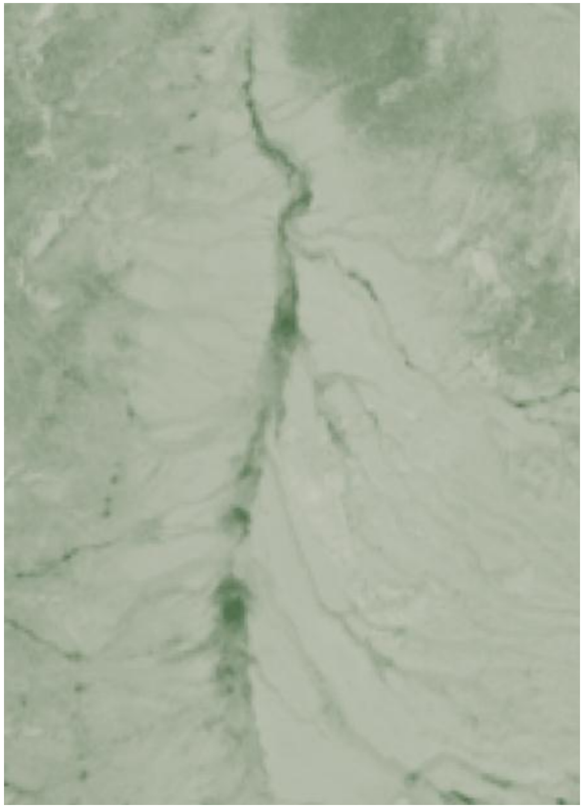
Results - Boulder Flat Phreatophyte Vegetation Increase



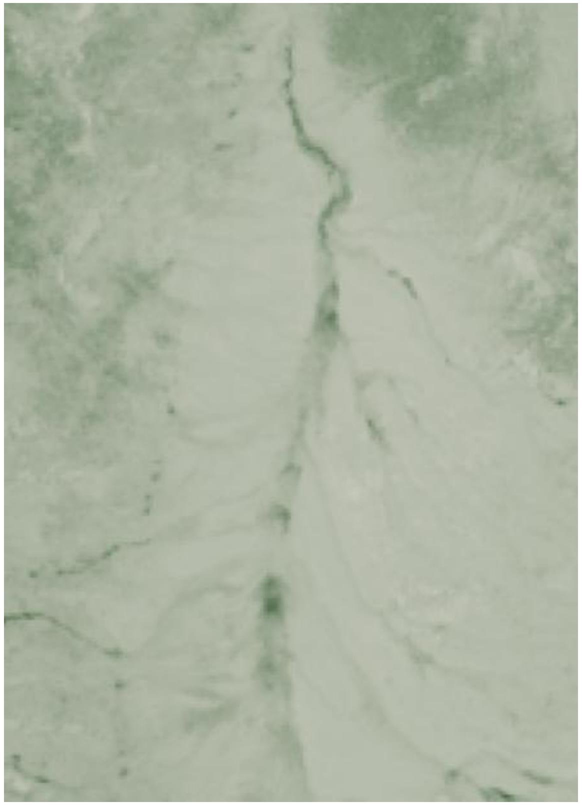


- Recharge of mine water up gradient started ~ 1991, and created springs down gradient
- GW levels increase sharply in 1992
- EVI increases in 1992-1994 and flucutates with PPT thereafter https://earthengine.google.org/#timelapse/v=40.89805,-116.40323,9.596,latLng&t=0.50

Landsat for Sage-Grouse Sensitive Areas



2013 July-Aug Max NDVI



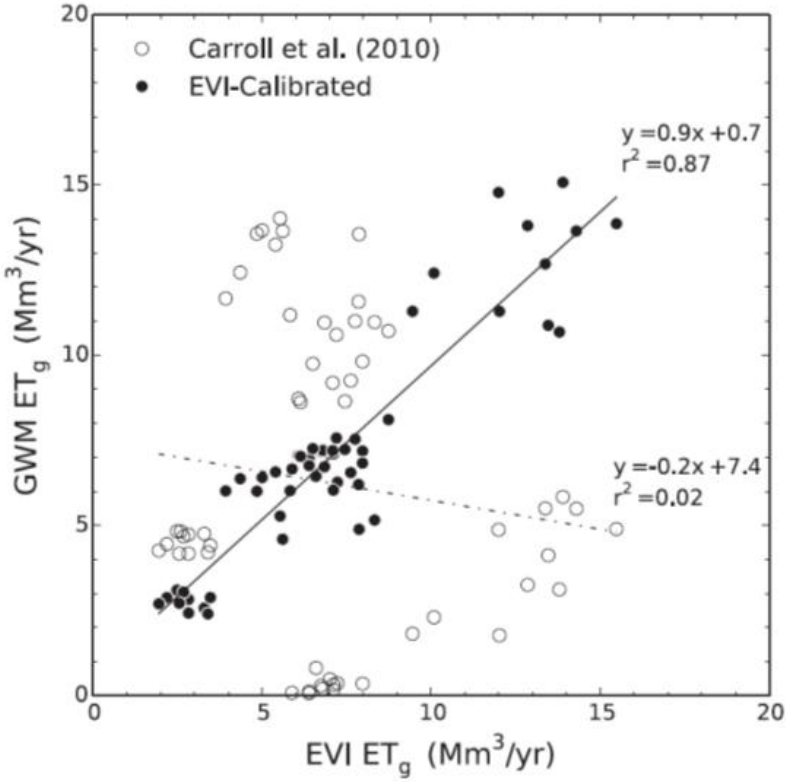
2014 July-Aug Max NDVI

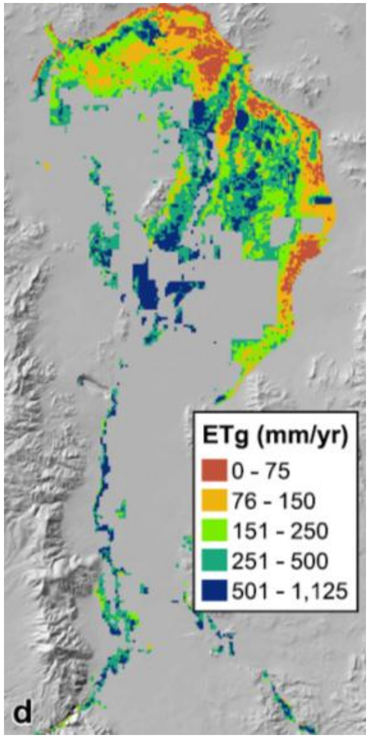
Indian Valley, NV - supports the largest Sage-Grouse lek in NV

Which areas are resilient to extended droughts?

Groundwater Modeling and Landsat

- Groundwater models need boundary conditions and calibration to observations
- Landsat can be used to help develop boundary conditions (recharge & groundwater pumping) and calibration targets (observations of ETg / shallow groundwater / water surfaces)
- Calibrated vs un-calibrated MODFLOW simulated ETg compared to Landsat derived ETg for Mason Valley, NV

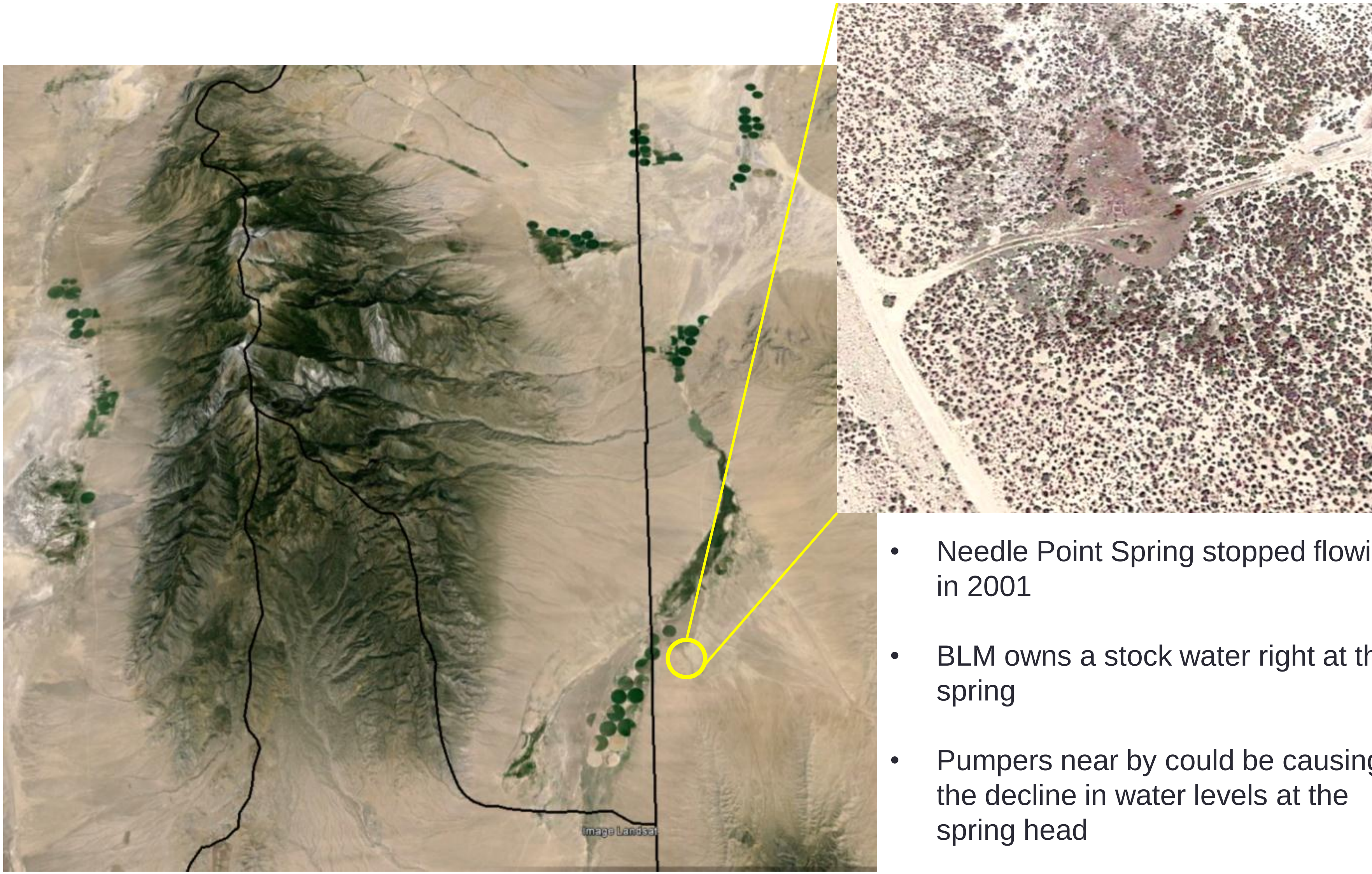




Carroll, R, G. Pohll, C. Morton, and J. Huntington, 2015. Calibrating a Basin-Scale Groundwater Model to Remotely Sensed Estimates of Groundwater Evapotranspiration. *Journal of the American Water Resources Association (JAWRA)* 1-14. DOI: 10.1111/jawr.12285

Groundwater Modeling – Needle Point Spring, UT

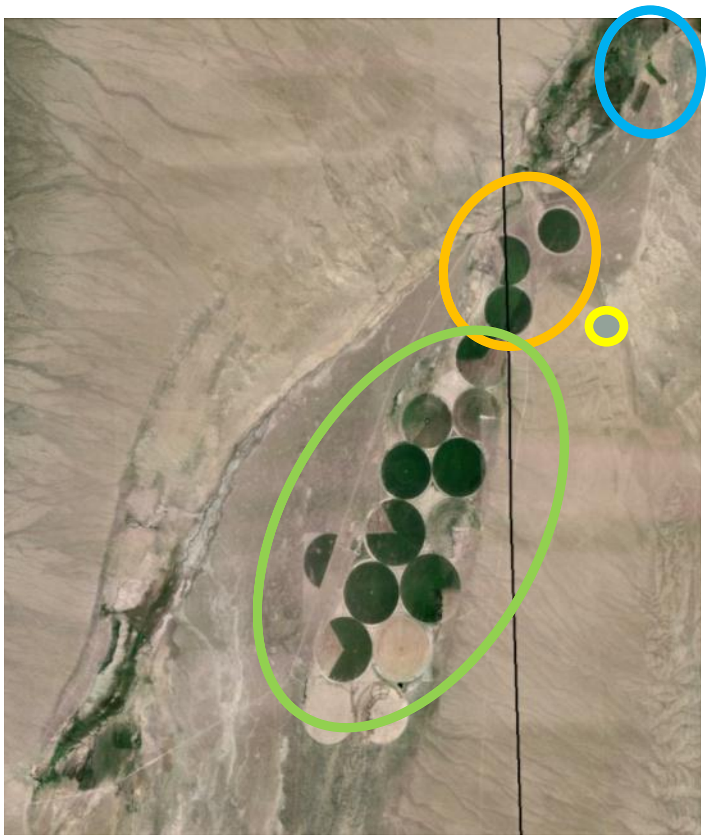
- https://earthengine.google.org/#timelapse/v=38.74288,-114.04747,10.812,latLng&t=0.61



- Needle Point Spring stopped flowing in 2001
- BLM owns a stock water right at the spring
- Pumpers near by could be causing the decline in water levels at the spring head
- Hearing just held at NV State Engineer’s Office

Groundwater Modeling – Needle Point Spring, UT

- USGS simulated water level declines at the spring while considering all the different pumpers near by



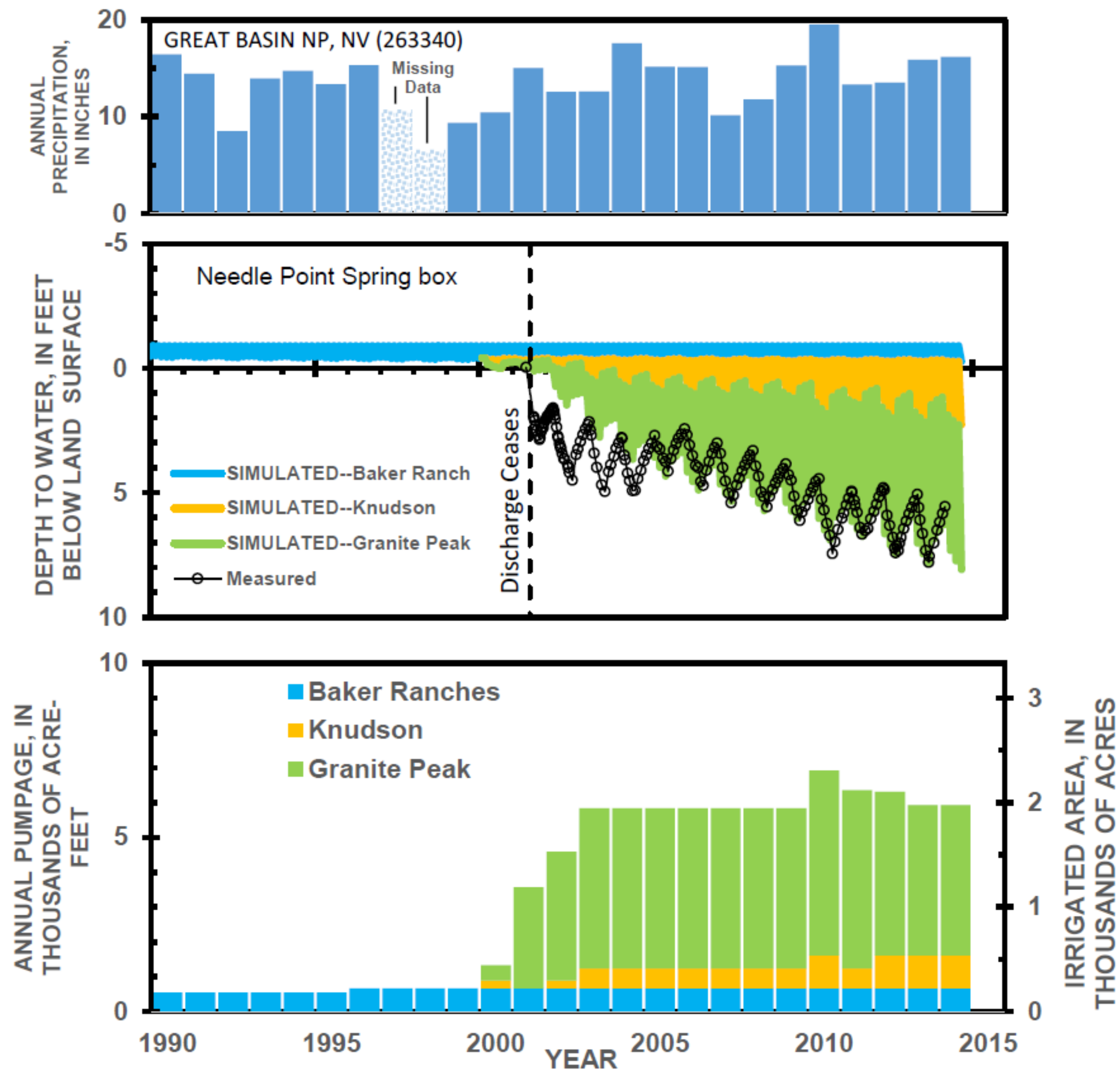
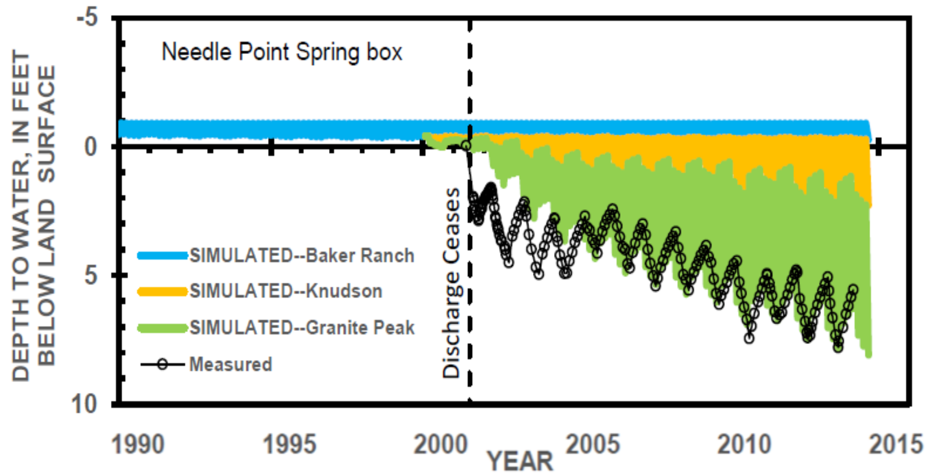


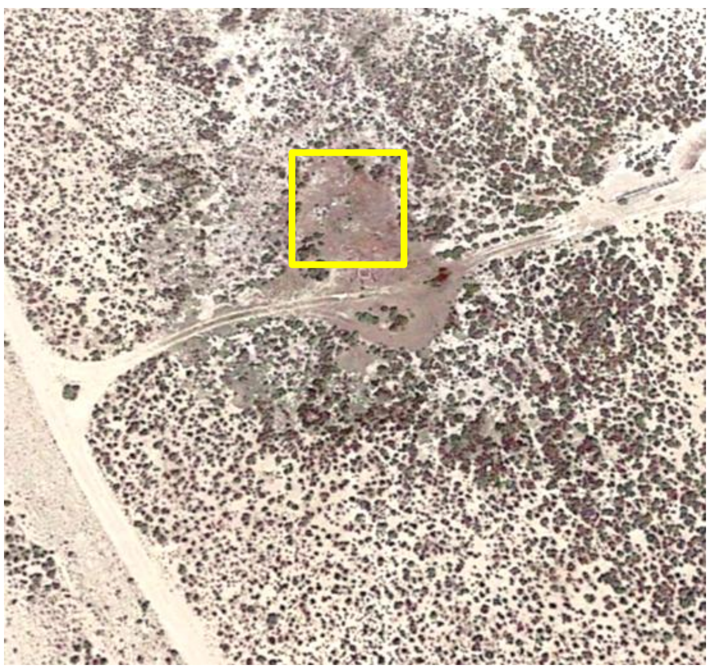
Figure from Keith Halford, 2015

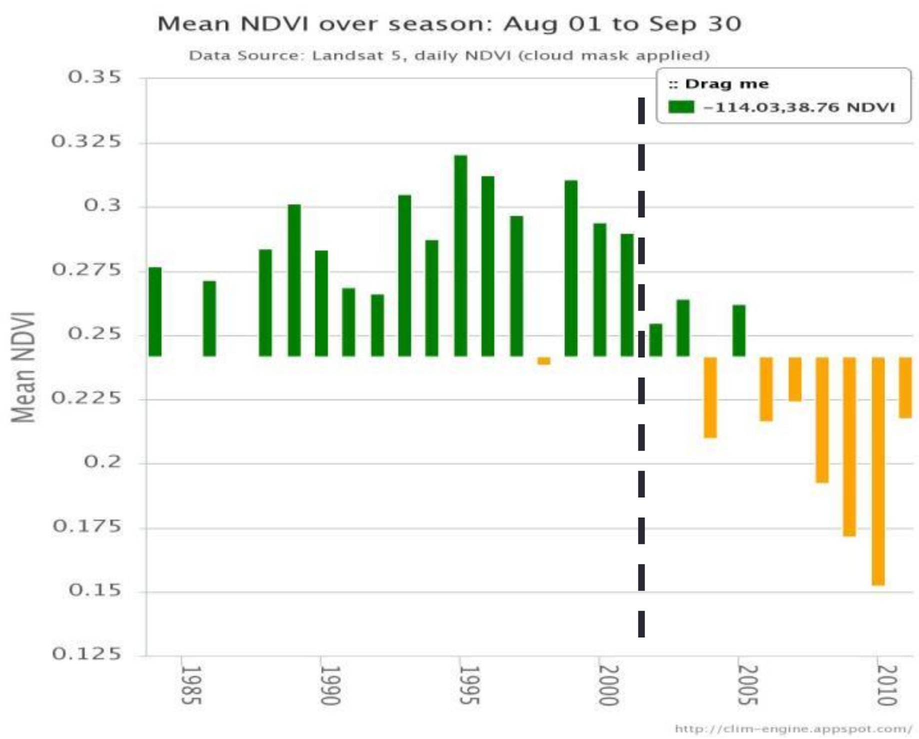
Climate and Remote Sensing Tool for Monitoring

- Google App Engine / Earth Engine web application was developed to mine the Landsat and other remote sensing and gridded weather data archives in the cloud

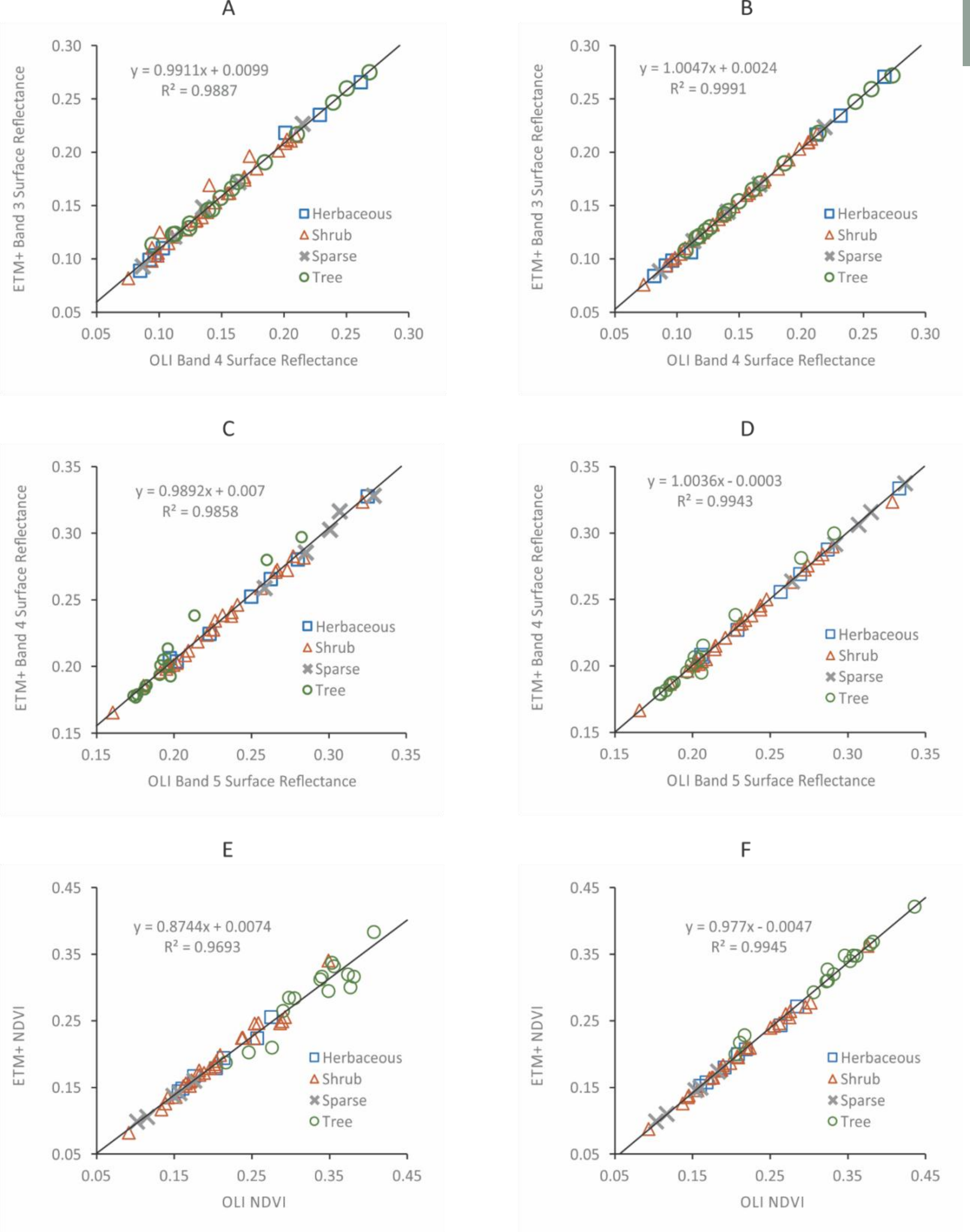
- The application was applied to Needle Point Spring to evaluate the decline of Landsat summer NDVI at the spring and compared to declines in measured and simulated groundwater levels







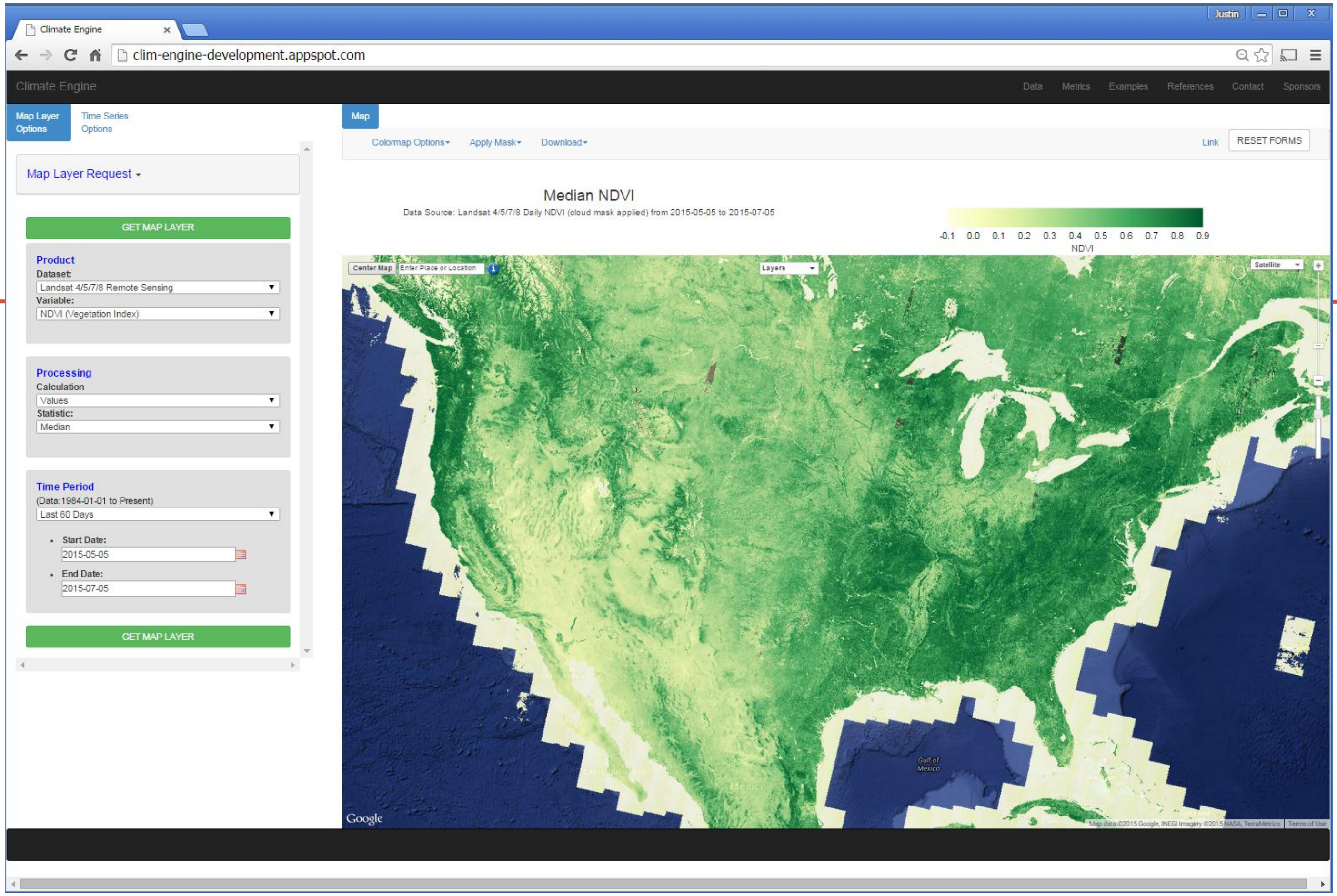
Under-fly Comparison



- WRS-2 path 38 from rows 31–38, spanned the Great Salt Lake to Mexico
- ESPA surface reflectance product in first column
- Tasumi et al. (2008) and Trezza et al. (2015) surface reflectance in second column
- Scatter in the ESPA plots is likely due to the mixing of atmospheric correction methods between sensors or perhaps a problem that the current version of the L8SR software has in mountainous terrain?

ClimateEngine.org

CLOUD COMPUTING AND VISUALIZATION OF CLIMATE AND REMOTE SENSING DATA



Landsat 7 & 8 Median NDVI for the last 60 days

How We Started, Motivation, Our Team

How We Started

- Our project was funded through a Google Faculty Research Award in Summer of 2014

Motivation

- Develop a web application that allows the public to visualize maps and time series of climate and remote sensing archives together and in real-time, for drought, vegetation, climate analysis, and ***data discovery***

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University of Idaho

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- Web application relies on Google App Engine, Google Maps API, and Google Earth Engine
- Google App Engine is linked to Google Earth Engine through the Python API and allows for on demand parallel cloud computing
- Users input collection and time parameters -> Google App Engine passes these parameters to Google Earth Engine -> results return to Google App Engine
- We started with the Hello World SRTM DEM Google App Engine - Google Earth Engine example outlined in the documentation

ClimateEngine.org

- Climate collections available through Google Earth Engine
  - UI METDATA / gridmet gridded daily weather data (CONUS)
  - Climate Forecast System Reanalysis - CFSR (Global)
  - CHIRPS Precipitation (Global)
- Remote sensing collections available through Google Earth Engine
  - Landsat 4, 5, 7, 8
  - MODIS Terra
- Products available through Google Earth Engine
  - UI METDATA / gridmet - daily precipitation, solar radiation, humidity, wind speed, reference ET, PDSI, others..
  - CFSR - 6 hourly land surface fluxes and states (all major ones)
  - CHIRPS – 5 day precipitation
  - Landsat and MODIS - NDVI, NDSI, NDWI, burn indices, fractional snow cover
- Map Calculations available
  - values
  - difference from average
  - percent difference from average
  - percent of average
  - percentile of distribution
- Time series calculations - daily, yearly summaries, intra-year comparisons of all collections and products
  - Allows for one or two products to be plotted at once

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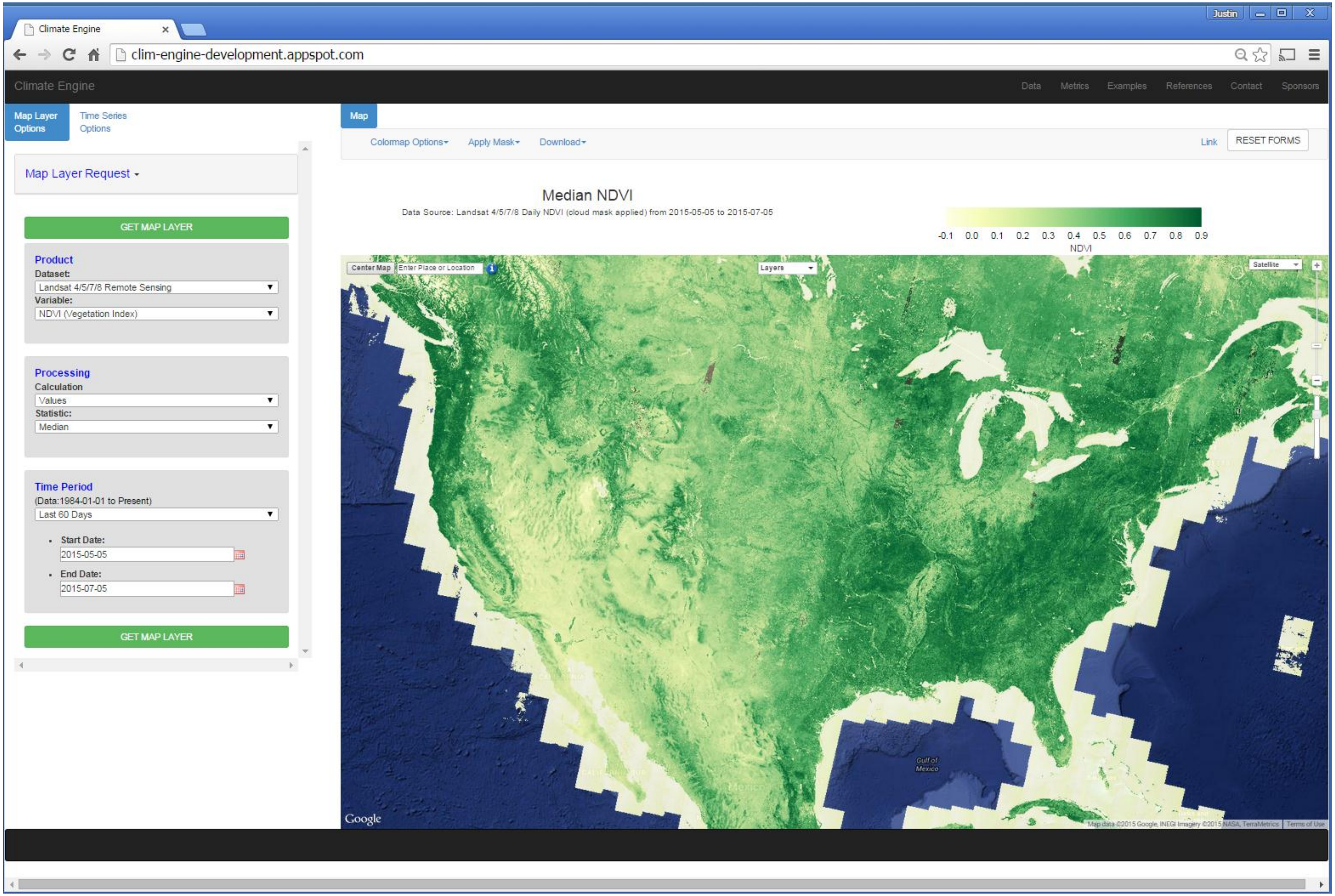
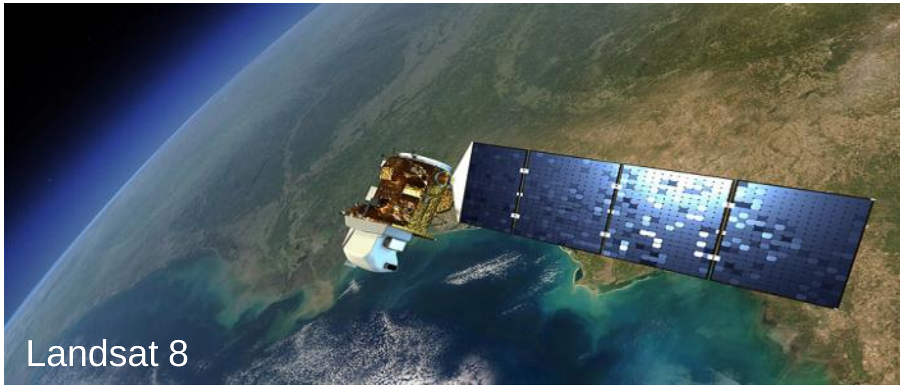
- [Demos]



Summary



- Even though we can’t see groundwater – it is important!!

- Use of groundwater modeling combined w/ remote sensing and climate archives will help better predict and monitor pumping and climate impacts on GDEs

- Google Earth Engine is really helping scientists, land managers, and the public access Landsat and climate archives to better monitor mother earth..

- ClimateEngine.org is just one new web application that can be used for climate and remote monitoring...

Many thanks to:
Landsat Science Team
Collaborators
Google
BLM
USGS/NASA
FEWSNET
NV Division of Water Resources
University of Idaho

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OLI and ETM+ Comparison Details

- Mask of the most consistent regions between the two sensors was required for inter-sensor calibration.
- Clouds and cloud shadows in both images were manually masked out with a buffer distance of approximately 1 km.
- Areas with a NIR reflectance of less than 0.05 were masked out to remove water bodies and areas of deep shadow that can be very noisy in ratios like NDVI.
- Pixels on either side of boundaries between classes in the LANDFIRE map were removed to reduce the influence of map misregistration, as well as misregistration between the two satellite overpasses in areas of high relief that arose from the offset in overpass position.
- Landfire classes whose masked area was less than 1000 pixels were removed from the analysis to ensure that a very stable mean value was calculated for each land cover class.
- The mean red, NIR, and NDVI for each vegetation class was calculated and OLI mean values were regressed against ETM+.